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Performance Comparison of RADARSAT-2 Advanced Moving Object Detection Experiment Modes

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Abstract

It has been recognized that a two-aperture approach to ground moving target indication is sub-optimum and that target parameter estimation is often compromised by clutter interference or poor signal-to-clutter ratios. This paper investigates the Ground Moving Target Indication (GMTI) performance of several virtual channel concepts proposed for the RADARSAT-2 Moving Object Detection EXperiment (MODEX). These are capable of increasing the spatial diversity of RADARSAT-2 by exploiting its very flexible antenna programming capabilities and allowing the two-channel SAR system to operate like a three or four channel radar. A high fidelity Space-Based Radar Moving Target Indication Simulator (SBRMTISIM) is used to generate virtual channel raw GMTI data for analysis. Moving targets are detected using a combination of the Factored Space-Time Adaptive Processing (Factored STAP) and the Cell-Averaging Constant False Alarm Rate (CA-CFAR) detector. The detection performances of virtual multichannel MODEX modes are analyzed and compared with each other and with those of true or fictitious multichannel space-based radar systems.

Résumé

On a reconnu que la technique des deux ouvertures n'est pas optimale pour l'indication de cibles terrestres mobiles et que l'estimation des paramètres des cibles est souvent compromise par le brouillage dû au clutter ou par de faibles rapports signal/clutter. Le présent document traite des performances d'indication de cibles terrestres mobiles (GMTI) de plusieurs concepts à canaux virtuels proposés pour l'expérience de détection des objets mobiles (MODEX) de RADARSAT-2. Ces concepts peuvent accroître la diversité spatiale de RADARSAT-2 en mettant à profit sa très grande souplesse de programmation d'antenne et en permettant de faire fonctionner le système SAR à deux canaux comme un radar à trois ou à quatre canaux. Un simulateur d'indication de cibles mobiles de radar spatial (SBRMTISIM) de grande fidélité est utilisé pour générer des données GMTI brutes de canal virtuel à des fins d'analyse. Les cibles mobiles sont détectées au moyen d'une combinaison du traitement adaptatif espace-temps (STAP) pondéré et du détecteur de taux de fausse alarme constant à pondération sur cellule (CA-CFAR). Les performances de détection des modes MODEX multicanaux virtuels sont analysées et comparées entre elles et avec celles de systèmes radar spatiaux multicanaux réels ou fictifs.

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Executive summary

Performance Comparison of RADARSAT-2 Advanced Moving Object Detection Experiment Modes

S. Chiu; DRDC Ottawa TM 2007-320; Defence R&D Canada – Ottawa; December 2007.

Background: A space-based radar imparts a significant clutter Doppler spread due to its high platform velocity (typically 7 km/s) and a large footprint on the earth. This Doppler spread interferes with detection of moving targets. Therefore, efficient ground moving target indication (GMTI) and target parameter estimation only is possible after sufficient clutter suppression. This is accomplished, in its simplest form, using two radar receiver channels, such as the dual receive antenna mode of RADARSAT-2's MODEX. However, the two-channel system is sub-optimum for simultaneous suppression of the clutter and estimation of targets' properties. This deficiency has led to exploration of means of increasing the spatial diversity for RADARSAT-2. One such method is the so-called sub-aperture "switching" or "toggling" to create multiple virtual channels.

Principal results: In this paper, we investigate and compare the GMTI performance of several proposed virtual multichannel modes (for the RADARSAT-2 MODEX) against each other and against true or fictitious multichannel radar systems and the standard two-channel MODEX mode. A high fidelity Space-Based Radar Moving Target Indication Simulator (SBRMTISIM) is used to generate virtual channel raw GMTI data for analysis. Moving targets are detected using a combination of the Factored Space-Time Adaptive Processing (Factored STAP) and the Cell-Averaging Constant False Alarm Rate (CA-CFAR) detector. The results show that there is a small (i.e. statistically insignificant) difference in the detection performance between the virtual multichannel modes and their corresponding true or fictitious multichannel radars with the same transmit/receive aperture sizes and along-track baselines. The difference is more noticeable in the three-channel toggle-receive architecture. In general, it can be concluded that the detection performance of a virtual multichannel GMTI radar is comparable to that of a true or fictitious multichannel GMTI radar. Comparison between the virtual multichannel modes, including the standard two-channel MODEX mode, shows that the three-channel toggle-transmit mode has a clear detection advantage over the other three proposed MODEX architectures. This can be attributed to a combination of increased spatial diversity and large along-track baselines.

Through simulations, this investigation has shown that the sub-aperture switching or toggling is a viable technique to improve GMTI performance via increased along-track baselines and spatial degrees of freedom. It is also shown in this study that Space-Time Adaptive Processing (STAP) algorithms such as the Factored STAP can be applied successfully to RADARSAT-2-like GMTI data to detect slowly moving ground targets. The result

puts to rest the concern that STAP techniques, which usually utilize much shorter pulse-integration times, may not be as effective in detecting moving targets as SAR-GMTI approaches, such as SAR along-track interferometry (SAR-ATI) and SAR displaced phase center antenna (SAR-DPCA).

Significance of results: The ability to simultaneously detect moving targets and determine their spatial coordinates and velocity parameters will certainly augment Intelligence, Surveillance and Reconnaissance (ISR) capabilities. A multiple aperture radar permits this feat to be accomplished through exploitation of spatial diversities. However, the effectiveness or the GMTI performance of a virtual multiple aperture radar, realized via sub-aperture toggling, still remains to be established for RADARSAT-2 antenna parameters and noise figures. Also, there is no report, as far as we know, of direct comparison between the virtual and true multiple aperture radar systems in the open literature. In this report, the modeling and simulations of various virtual multiple aperture modes for the RADARSAT-2 MODEX have shown positive results, indicating that these virtual modes have comparable GMTI performances with respect to corresponding true multiple aperture radar systems.

Sommaire

Performance Comparison of RADARSAT-2 Advanced Moving Object Detection Experiment Modes

S. Chiu ; DRDC Ottawa TM 2007-320 ; R & D pour la défense Canada – Ottawa ; décembre 2007.

Introduction : Un radar spatial crée un important étalement Doppler du clutter attribuable à la vitesse élevée de sa plate-forme (généralement 7 km/s) et une large empreinte au sol. Cet étalement Doppler nuit à la détection des cibles mobiles. Par conséquent, l'indication des cibles terrestres mobiles (GMTI) et l'estimation des paramètres des cibles ne peuvent être réalisées de manière efficace qu'après une suppression adéquate du clutter. Sous sa forme la plus simple, cette suppression s'effectue au moyen de deux canaux de récepteur radar, par exemple dans le mode à antenne de réception double utilisé pour l'expérience MODEX de RADARSAT-2. Cependant, le système à deux canaux n'est pas optimal pour effectuer simultanément la suppression du clutter et l'estimation des propriétés des cibles. Pour combler cette lacune, on a étudié des moyens d'accroître la diversité spatiale de RADARSAT-2, notamment la méthode dite de « basculement » ou de « commutation » sous-ouverture de création de canaux virtuels multiples.

Résultats : Le présent document porte sur l'étude des performances d'indication de cibles terrestres mobiles de plusieurs modes multicanaux virtuels proposés (pour l'expérience MODEX de RADARSAT-2) et sur la comparaison de ces performances entre elles et par rapport à celles de systèmes radar multicanaux réels ou fictifs et à celles du mode MODEX à deux canaux standard. Un simulateur d'indication de cibles mobiles de radar spatial (SBRMTISIM) de grande fidélité est utilisé pour générer des données GMTI brutes de canal virtuel à des fins d'analyse. Les cibles mobiles sont détectées au moyen d'une combinaison du traitement adaptatif espace-temps (STAP) pondéré et du détecteur de taux de fausse alarme constant à pondération sur cellule (CA-CFAR). Les résultats montrent une légère différence (c.-à-d. non significative du point de vue statistique) au chapitre des performances de détection entre les modes multicanaux virtuels et les radars multicanaux réels ou fictifs correspondants ayant les mêmes ouvertures d'émission/de réception et lignes de base longitudinales. La différence est plus perceptible avec l'architecture de réception par basculement à trois canaux. De manière générale, on peut conclure que les performances de détection d'un radar GMTI multicanaux virtuel sont comparables à celles d'un radar GMTI multicanaux réel ou fictif. La comparaison des modes multicanaux virtuels, y compris du mode MODEX à deux canaux standard, montre que le mode d'émission par basculement à trois canaux offre un net avantage au chapitre de la détection par rapport aux trois autres architectures MODEX proposées. Cet avantage peut être attribué à une combinaison de diversité spatiale accrue et de lignes de base longitudinales étendues.

Cette étude a démontré de façon concluante que la commutation ou le basculement de sous-ouverture constitue une technique viable pour améliorer les performances de GMTI par l'accroissement des lignes de base longitudinales et des degrés de liberté spatiaux. Elle a montré également que les algorithmes de traitement adaptatif espace-temps (STAP), par exemple les algorithmes STAP pondéré, peuvent être appliqués efficacement à des données GMTI semblables à celles de RADARSAT-2 pour la détection de cibles terrestres lentes. Ce résultat est important, car on croyait auparavant que les techniques STAP avec des temps d'intégration d'impulsion beaucoup plus courts pourraient ne pas être aussi efficaces pour la détection des cibles mobiles que les techniques SARGMTI, par exemple l'interférométrie longitudinale par SAR (SARATI) et l'utilisation de l'antenne à centre de phase déplacé SAR (SAR-DPCA). Les résultats montrent clairement que la technique STAP constitue une solution de rechange viable aux méthodes SAR-GMTI non adaptives de traitement des données MODEX de RADARSAT-2.

Portée : La capacité de détecter des cibles mobiles et, simultanément, déterminer leurs coordonnées spatiales et leurs paramètres de vitesse accroîtrait assurément les capacités de renseignement, surveillance et reconnaissance (RSR). Le radar multi-ouvertures offre cette possibilité en exploitant les diversités spatiales. Toutefois l'efficacité ou le rendement de l'indication de cibles terrestres mobiles d'un radar multi-ouvertures virtuel — synthétisé en basculant d'une sous-ouverture à l'autre — reste à prouver pour les paramètres d'antenne et les facteurs de bruit de RADARSAT-2. Nous ne connaissons aucune publication scientifique où l'on compare directement les radars multi-ouvertures virtuels à leur contrepartie matérielle. Dans le présent rapport, nous présentons la modélisation et des simulations de différents modes d'ouvertures virtuelles pour RADARSAT-2 en mode MODEX, lesquelles ont toutes montré des résultats positifs indiquant que, sur le plan de l'indication de cibles terrestres mobiles, les radars virtuels présentaient un rendement comparable à celui des radars multi-ouvertures matériels.

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1 Introduction

Due to the significant clutter Doppler spread that is imparted by a fast-moving space-based radar (SBR) platform (typically 7 km/s) and the large footprints that result from space observation of the earth, strong mainbeam clutter will impede the detection of even large air and ground targets, while sidelobe clutter will hinder the detection of small targets. Efficient ground moving target indication (GMTI) and target parameter estimation can be achieved only after sufficient suppression of interfering clutter, particularly for space-based SARs with typically small exo-clutter regions. In its simplest form, this is accomplished using two radar receiver channels, such as the dual receive antenna mode of RADARSAT-2's Moving Object Detection EXperiment (MODEX). In this mode of operation, the full antenna is split into two sub-apertures with two parallel receivers to create two independent phase centers. It is known, however, that two degrees of freedom are sub-optimum for simultaneous suppression of the clutter and estimation of targets' properties, such as velocity and position [1]. Parameter estimation of moving targets is often compromised and limited by clutter interference [2]. This deficiency has led to exploration of means of increasing the spatial diversity for RADARSAT-2. One such method is the so-called sub-aperture “switching" or “toggling" to create virtual channels [3]. The proof of concept for this technique was demonstrated using both simulation and experimental two-channel GMTI data in [4]. In this paper, we investigate and compare the GMTI performance of several proposed virtual multichannel modes (for the RADARSAT-2 MODEX) against each other and against true or fictitious multichannel radar systems.

The 512 Transmit/Receive Modules (TRMs) in the RADARSAT-2 two-dimensional active phased array are organized as 16 columns, as depicted by little green rectangles in Fig. 1, with 32 TRMs per column. All TRMs have independent control of transmitter/receiver (Tx/Rx) phase and amplitude for both vertical and horizontal polarizations. The control of phase and amplitude in the elevation dimension allows for the formation and steering of all beams. Transmitter phase control in the azimuth dimension allows the formation of the wider beams required for the Ultrafine resolution mode. This is accomplished by the deliberate defocussing of the beam.

The proposed virtual channel modes take advantage of the flexible programming capabilities of the RADARSAT-2 antenna to generate third and fourth channels, as illustrated in Fig. 1(b-d). The spatial diversity can be increased either by transmitter toggling between pulses, Fig. 1(b), or by smart receiver excitation schemes, Fig. 1(c&d). These are only a few methods for achieving multichannel capability and are by no means exhaustive. Due to the transmitter/receiver toggling between pulses, the pulse repetition frequency (PRF) is cut by one half. This may lead to clutter band aliasing due to sub-Nyquist sampling, but can be compensated for by doubling the original PRF as indicated in Fig. 1. The tradeoffs for the increased spatial diversity are a reduced maximum range swath and increased range and azimuth ambiguities (Fig. 2). The range ambiguity is caused by higher PRFs of the

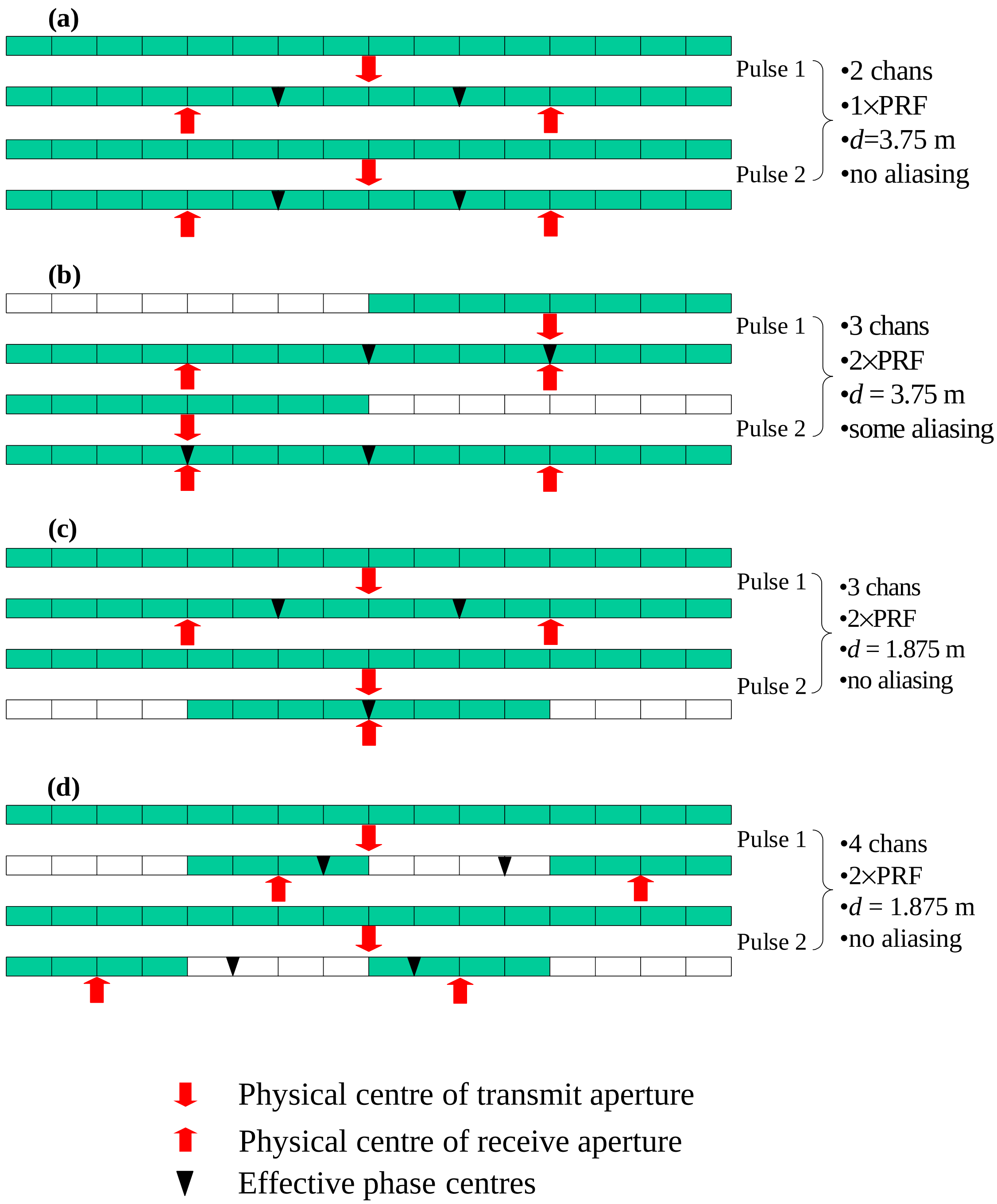


Figure 1: *RADARSAT-2 multichannel modes: (a) standard two-channel receive mode, (b) three-channel toggle-transmit mode, (c) three-channel toggle-receive mode, and (d) four-channel toggle-receive mode. Green rectangles constitute active antenna columns; red arrows represent transmitter/receiver physical centers; and black inverted triangles denote two-way effective phase centers.*

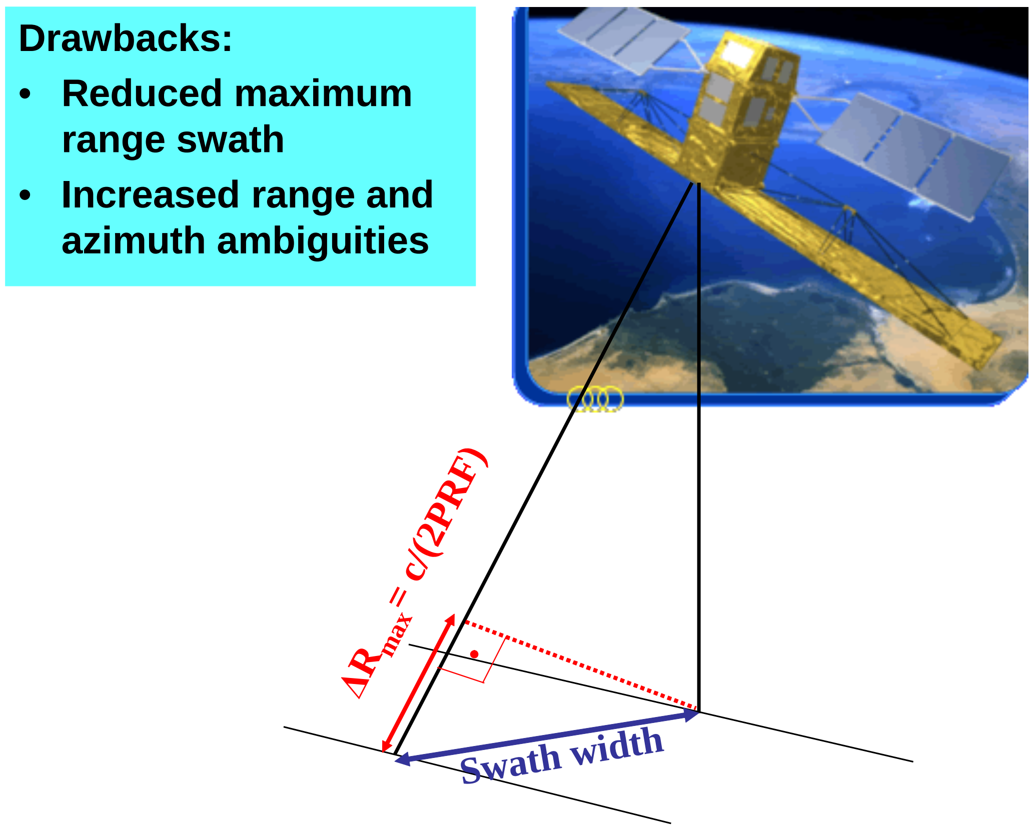


Figure 2: *The tradeoffs for an increased spatial diversity are a reduced maximum range swath and increased range and azimuth ambiguities.*

toggling modes and the azimuth ambiguity is mainly due to the possible inadequate sampling of the clutter band caused by the beam broadening in the azimuth dimension. Range ambiguities in synthetic aperture radar (SAR) images can, however, be eliminated with an azimuth filter after having applied an azimuth phase modulation to the transmitted pulses and a corresponding demodulation to the received pulses [5].

The transmitter toggling (between fore and aft sub-apertures) approach, Fig. 1(b), has the advantage of maintaining the same inter-phase-center distance (or the along-track baseline) as the standard dual-channel mode (Fig. 1(a)), which is 3.75 m for the RADARSAT-2, and is capable of generating three independent phase centers, shown as upsidedown black triangles. The red arrows denote the Tx/Rx physical center positions. The two-way beamwidth is significantly broadened for the toggle-transmit case, compared to the standard dual-channel mode (see Fig. 3), due to the half-aperture transmit and the half-aperture receive (see Fig. 1(b)). This could potentially lead to clutter band aliasing even at RADARSAT-2's maximum PRF, which is 3800 Hz. However, calculations seem to in-

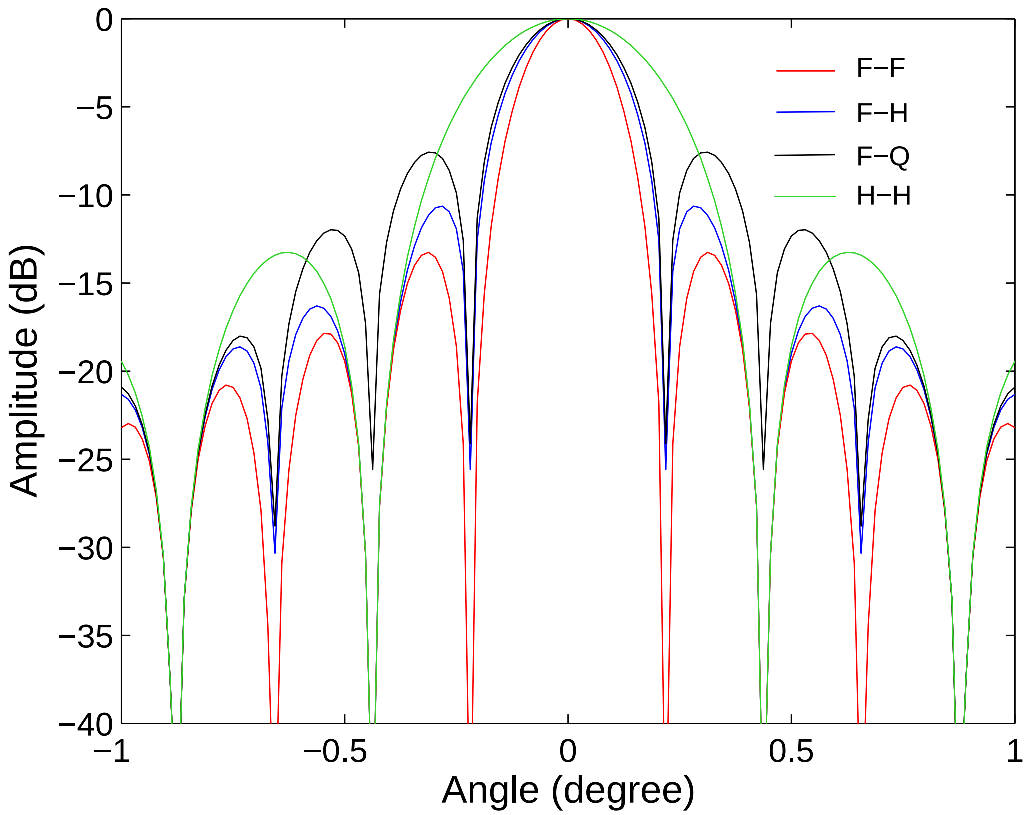


Figure 3: *The antenna patterns of different transmit and receive sub-aperture combinations: "F-F" full-aperture Tx and full-aperture Rx, "F-H" full-aperture Tx and half-aperture Rx, "F-Q" full-aperture Tx and quarter-aperture Rx, and "H-H" half-aperture Tx and half-aperture Rx.*

dicate that the 3-dB main-beam can be adequately (Nyquist) sampled at 3112.56 Hz (or 1556.28 Hz per channel), which is well below the maximum PRF limit of the radar. The transmitter toggling will, however, decrease the transmit power and hence may limit the required signal-to-noise ratio (SNR).

The second and third approaches are three- and four-channel toggle-receive modes (Fig. 1 (c&d)) where pulses are transmitted at full aperture and returns are received using two different alternating receiver excitation schemes. Both methods produce an inter-phase-center distance that is half of the original dual-channel case. The only differences between the two approaches are the number of phase centers generated and the slightly different two-way antenna patterns (blue and black lines in Fig. 3). There is very little main-beam broadening even for the four-channel case. Sidelobe levels, however, experience an up-to-5 dB increase compared to the case of full-aperture transmit and half-aperture receive.

2 Space-Based Radar MTI Simulator

SBRMTISIM [6][7], a spaceborne SAR-GMTI simulator, is used to generate multichannel RADARSAT-2-like GMTI raw data. SBRMTISIM is a comprehensive system and signal level design and analysis tool for Space-Based Radar (SBR) applications. Radar signal performance is accurately predicted by simulating the complete mission scenario. Pulse waveform generation, antenna illumination, electromagnetic propagation to and from all targets and clutter, target and clutter backscatter, SBR orbital and target motion, as well as return signal processing and detection processes are all digitally implemented with high precision and fidelity. This tool includes processing algorithms such as pulse-Doppler, synthetic aperture radar (SAR), space-time adaptive processing (STAP) and displaced phase centre antenna (DPCA) processing. The STAP and DPCA algorithms make use of multiple antenna apertures and adaptive processing to reject the strong clutter returns that otherwise would make slow moving ground targets invisible to the radar.

3 Proof of the Concept

As stated earlier, the concept of using virtual channels to suppress the stationary clutter and improve the parameter estimation performance has been demonstrated in [4]. Here, we provide a brief summary of the results using simulation.

The SBRMTISIM spaceborne GMTI simulator is used to generate RADARSAT-2-like SAR raw data. The proposed 3-channel toggle-transmit mode (Fig. 1(b)) is simulated. The signals received at three virtual phase centers are then processed using the three-channel along-track interferometry (ATI) [1] as depicted in Fig. 3. The channels are then registered with respect to channel 1 via the FFT data interpolation, shown as time delays in the figure. The t_{dpca} is the time taken by the platform to travel a distance equal to the along-track baseline between the (effective) phase centers. Fig. 5(a) shows the time-frequency plot of channel 1's range-compressed but azimuth uncompressed, target-plus-clutter signal. As can be seen in this figure, the target is not readily visible in the channel-1 signal due to clutter contamination. However, the interfering clutter can be cancelled using the virtual channels as seen in Fig. 5(b), where the second virtual channel is used to suppress the first channel's clutter via the Displaced Phase Center Antenna (DPCA) subtraction [8]. Figs. 5(c) and 5(d) show the azimuth-compressed signals before and after the clutter cancellation, respectively. The azimuth compression is achieved using the fractional Fourier transform [2] matched to the target velocity. Figs. 5(e) and 5(f) are polar plots of the interferograms before the clutter suppression (I_{12} or I_{23} in Fig. 3) and after the clutter suppression ($s(t)$ in Fig. 3). The clutter-contaminated case shows an ATI phase bias of about 4 degrees and also a large variance in the phase measurement, Figs. 5(e)&5(f), illustrating the need for the clutter nulling and the motivation for generating additional degrees of freedom from a two-physical channel radar system.

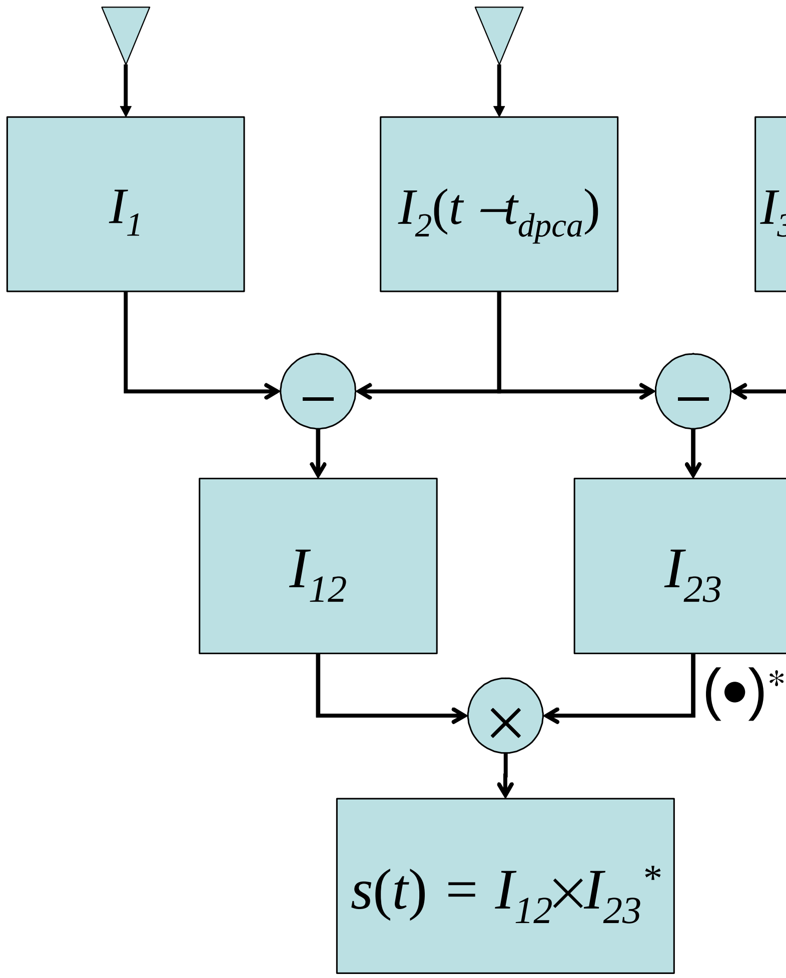


Figure 4: *A schematic of a three-channel SAR along-track interferometric processor*

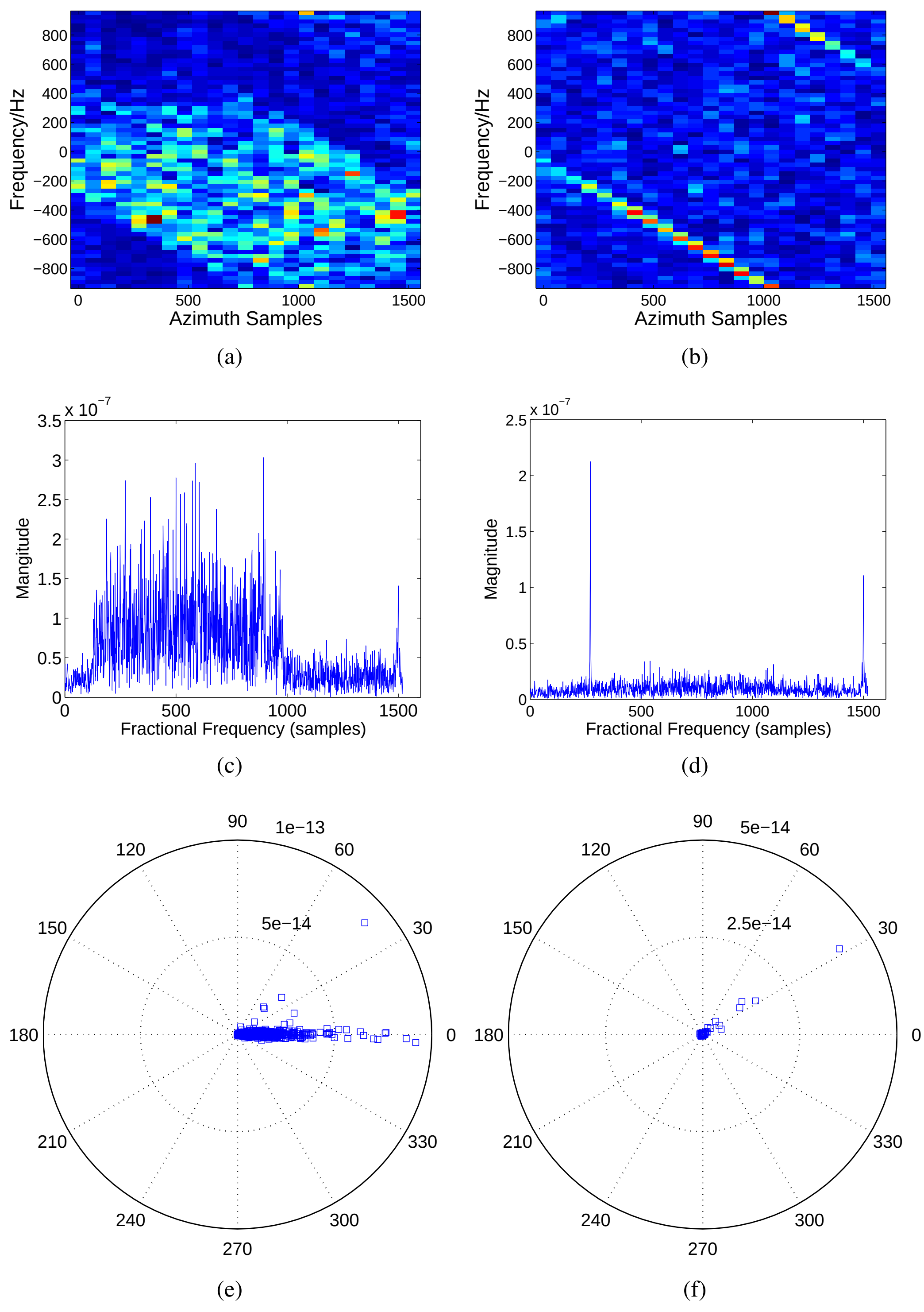


Figure 5: *Four-channel GMTI using toggle-receive mode.*

4 Detection Performance Comparison

The proposed toggle-transmit and toggle-receive modes are simulated by sampling alternately the odd and even pulses to form virtual channels as previously described. Ten ground moving targets, with velocities ranging from 40 to 100 km/h and RCSs from 40 to 100 m^2 (representing typical ground moving targets of interest), are modeled and raw signals are generated. The stationary clutter is modeled as K-distributed point scatterers with K-shape parameter equal to one. The mean clutter cross-section is 0.1 m^2/m^2.

A sub-optimal reduced dimension STAP architecture, namely the factored time-space (FTS) or Doppler factored STAP architecture, is chosen as the common GMTI processor for clutter nulling. Details of the algorithm can be found in [9]. After the STAP, the data is passed through the Cell-Averaging Constant False Alarm Rate (CA-CFAR) detector [10]. An example of detected targets is shown in Fig. 6 for the proposed 3-channel toggle-transmit mode. Nine out of ten targets are detected for this case.

The efficiency of any linear processor, like the factored STAP, can be characterized by the improvement factor (IF), which is defined as the ratio of signal-to-noise power ratios at the output and input, respectively [11]. We use the IF metric to compare the performances of the proposed virtual channel architectures against each other and against those of “true" or ideal multichannel radars (i.e., radars with true physical channels) to see if there is any noticeable performance degradation in using the sub-aperture switching technique to achieve the multichannel capability.

One must note here that the performance comparison does not take into account the significantly reduced maximum allowable range swath due to the doubling of the PRF. The detection performance comparison is made in terms of the STAP improvement factor, which translates to the number of detected targets. In a strict performance perspective, however, the loss of range swath may severely impact and restrict the utility of such a radar system (i.e. the virtual-channel radar) in an operational scenario.

4.1 Two-Channel Modes

We first compare three different two-channel modes (see Fig. 7). The first one is the standard dual-channel mode (Fig. 7a), which transmits at full aperture and receives simultaneously with two half apertures. The second case is a slight variation of the standard mode, which uses two quarter apertures at the far ends of the full aperture instead of half apertures at receive (Fig. 7b). The third mode is the two-channel toggle-transmit mode (Fig. 7c), which uses only two of the three generated phase centers to form a very large along-track baseline ($d = 7.5$ m).

The effect of increasing the baseline of the standard dual-channel mode, from 3.75 to 5.625 m, is not readily noticeable in the number of detected targets (Fig. 16, first two cases),

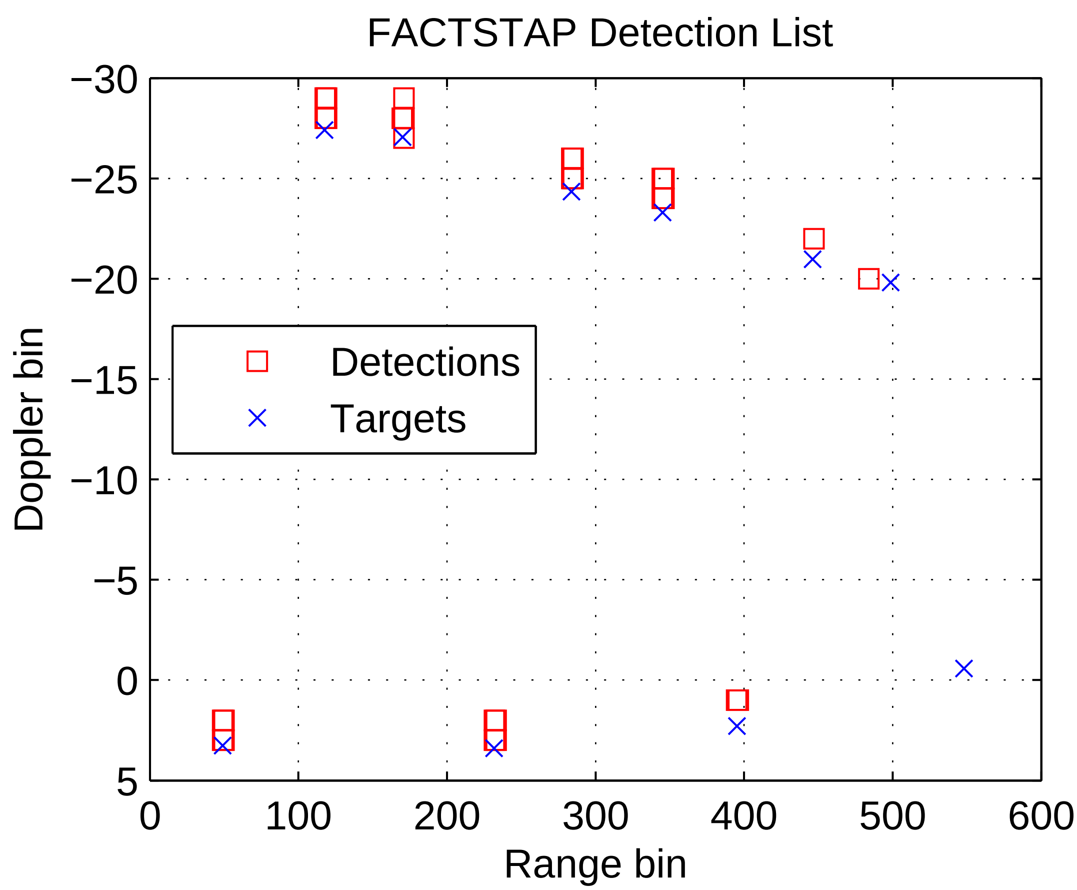


Figure 6: *Ten ground moving targets are detected in the three-channel toggle transmit mode. '×' denotes targets' actual range-Doppler positions.*

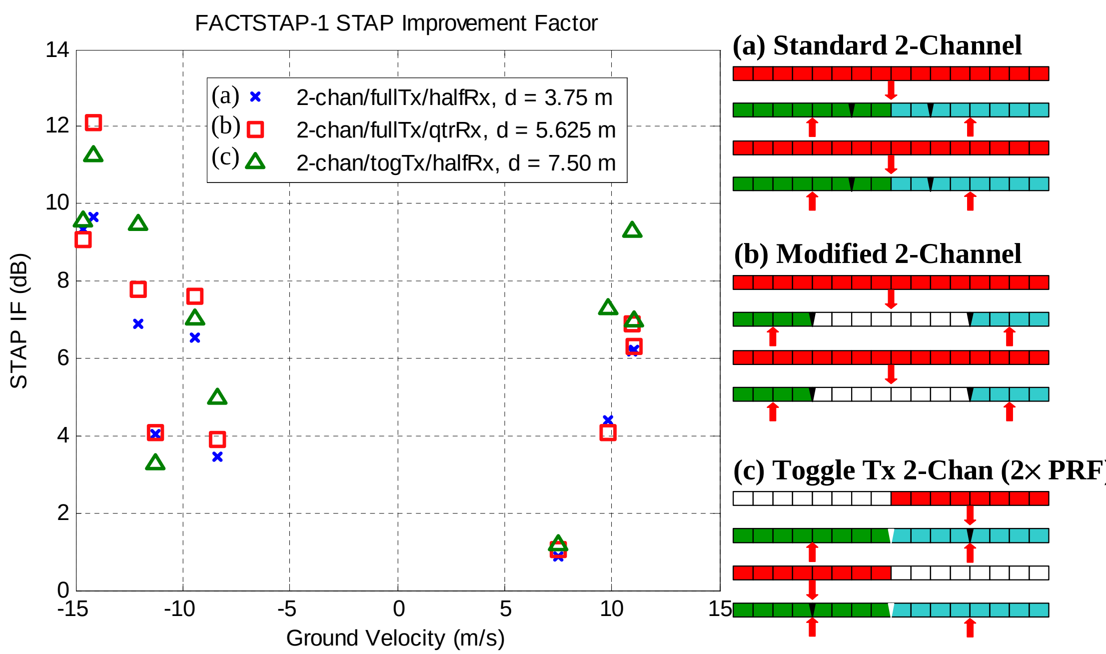


Figure 7: *The two-channel modes: (a) the standard dual-channel mode; (b) the slight variation of the standard mode, which uses two quarter apertures at far ends at receive; and (c) the toggle-transmit mode, which uses only two of the three generated phase centers to form a very large along-track baseline.*

but the IF plot does show a marginal performance improvement for the larger baseline case. This result seems to indicate that it may be advantageous to sacrifice some azimuth beamwidth (i.e. a slight broadening) for an increased along-track baseline between the phase centers. Similar observations can also be made in the case of the two-channel toggle-transmit mode. As stated earlier, the toggle modes use a pulse repetition frequency (PRF) that is twice that of the standard mode in order to keep the same PRF per channel. But since the two-way main beamwidth of the toggle-transmit mode is significantly broader (about 60%) than the standard mode, it is possible that some clutter spectrum may be aliased. But this drawback does not appear to offset the benefit of a very large baseline, which is manifested both in the increased number of detected targets (Fig. 16, case 3) and in the STAP IF (see Fig. 7(c)).

4.2 Three-Channel Modes

Next, we compare the three-channel toggle-transmit mode (Fig. 8(b)) against a ideal three-channel mode (Fig. 8(a)) of the same Tx/Rx aperture sizes and inter-phase-center distance. As can be seen in Fig. 8(a), the ideal mode has a total receiving antenna size that is larger than that permitted by the RADARSAT-2 in order to keep the same antenna parameters as the toggle-transmit mode. The only difference between the two modes is that the latter uses transmitter toggling to generate three independent phase centers and, therefore, requires twice the PRF in order to maintain the same number of pulses per “channel" (or phase center) as the ideal mode for a specified coherent processing interval (CPI). In general, the toggle-transmit mode does not perform as well as the ideal case for the range of target speeds examined, especially for slow movers as observed in poorer IFs (Fig. 8). This difference is also noticeable in the number of detected targets as the ideal three-channel architecture is able to detect all ten targets (Fig. 16, case 4) compared to only nine targets detected by the three-channel toggle-transmit mode (Fig. 16, case 5).

The above result may appear to be not a fair comparison because the ideal mode has not only three physical channels but also a larger receiving antenna compared to the three-channel toggle-transmit mode, which has only two physical channels and a smaller total receiving antenna. A fairer comparison could be made with a three-physical-channel radar system of the same total receiving antenna size as the toggle-transmit case. This is depicted in Fig. 9(c), where the RADARSAT-2 antenna is equally divided into three equal sub-apertures at receive with one physical channel per sub-aperture. It is clear from Fig. 9 that the toggle-transmit mode still shows the performance superiority, except at the lower velocity range. Also included in this comparison is the three-channel toggle-receive mode (Fig. 9(b)), which has the worst performance among the three different approaches, most likely because of its shortest along-track baseline.

We also compare this latter (toggle-Rx) mode with a ideal three-channel mode of the same antenna parameters (i.e. transmit with the full aperture and receive with half apertures) and

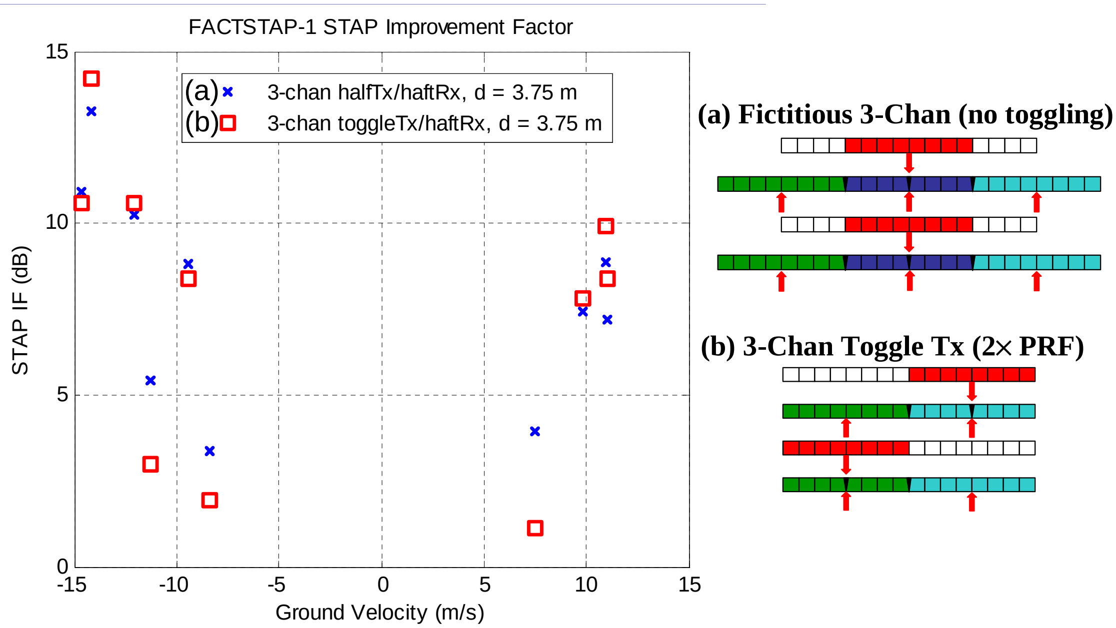


Figure 8: *STAP improvement factor: Fictitious 'three-channel' half-aperture transmit and three half-aperture receive at PRF = 1900 Hz compared to 'three-channel' half-aperture toggle Tx and two half-aperture receive at nominal PRF = 3800 Hz. 'd' is the along-track baseline between two-way effective phase centers.*

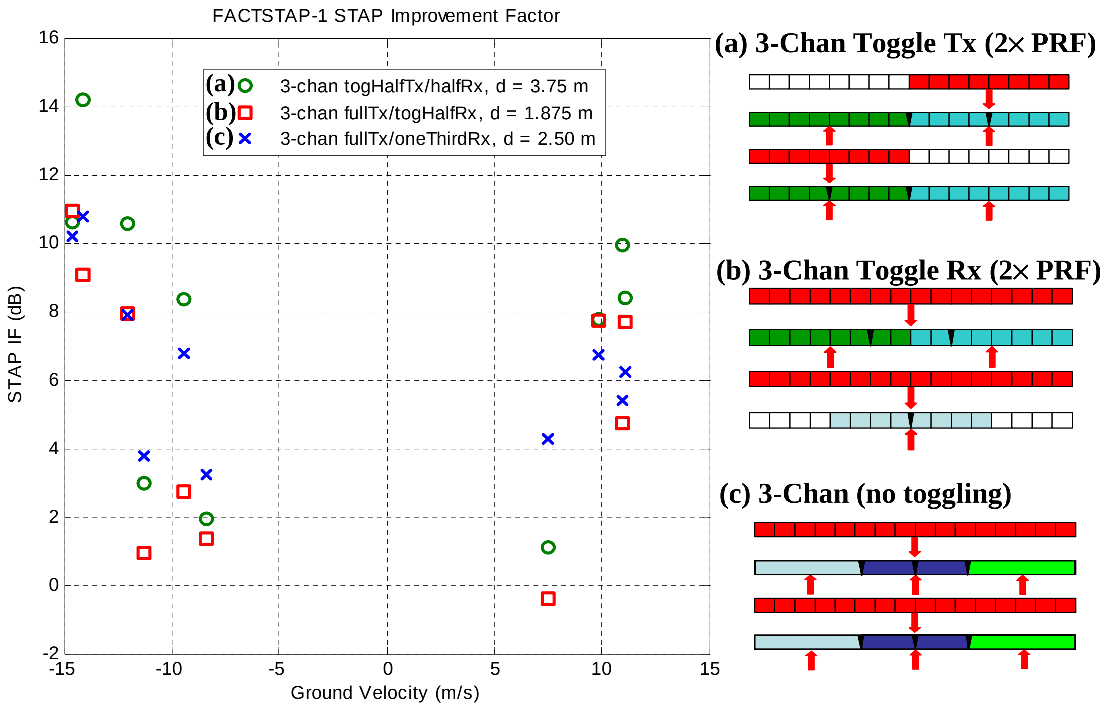


Figure 9: *An IF comparison: (a) the three-channel toggle-transmit mode, (b) the three-channel toggle-receive mode, and (c) a ideal three-channel (physical) mode.*

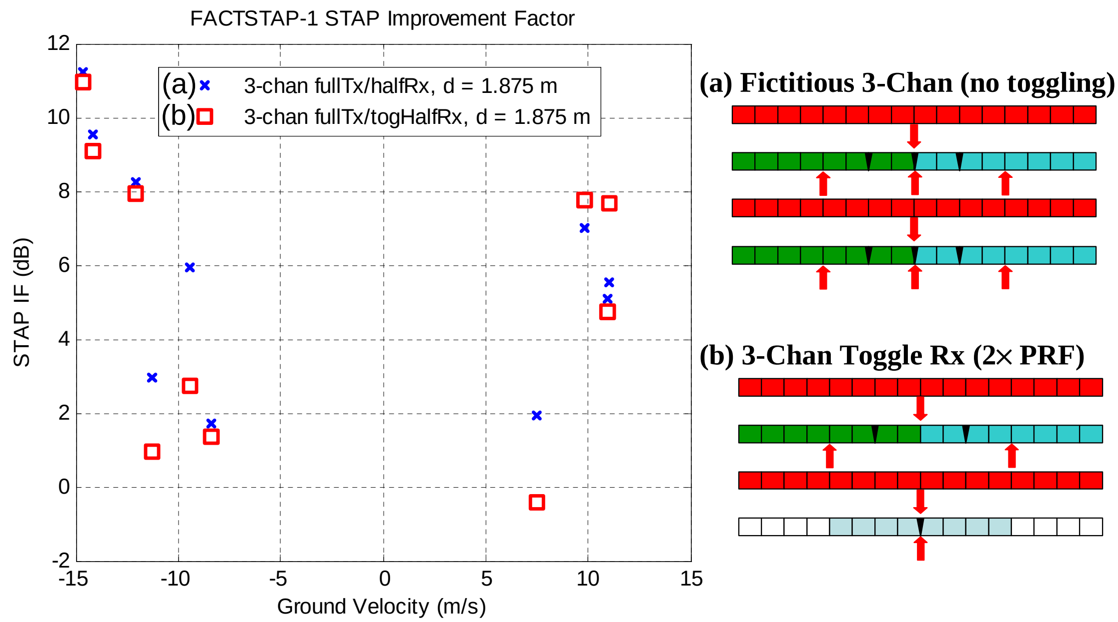


Figure 10: *STAP improvement factor: Fictitious 'three-channel' one full-aperture transmit and three half-aperture receive at PRF = 1900 Hz compared to 'three-channel' full-aperture transmit and one or two half-aperture toggle receive at PRF = 3800 Hz. 'd' is the along-track baseline between two-way effective phase centers.*

a same inter-phase-center distance ($d = 1.875$ m) in Fig. 10. For this three-channel ideal mode, the radar has three physical channels that accept signals received at fore, center, and aft half apertures to form three independent phase centers as depicted by three upside black triangles (Fig. 10a). The only difference between the two modes is that the toggle-Rx mode uses the sub-aperture switching at receive to generate three independent phase centers and has only two physical channels for reception. It is evident that the toggle-receive mode does not perform as well as the ideal mode for the range of target velocities tested, except for one case, which may be a statistical variation.

4.3 Toggle-Transmit Modes

We find that generally an increase in the along-track baseline appears to have an overall positive effect on the detection performance in all the different modes discussed so far, as evidenced in the superior performance of the toggle-transmit modes. We would like to examine this a bit further by modifying the three-channel toggle-transmit mode as shown in Fig. 11b. Here, radar echoes are received using two quarter apertures at far ends, instead of the two half apertures, in order to further increase the along-track baseline from 3.75 to 5.625 m. As can be seen in the figure, the further increase in the inter-phase-center

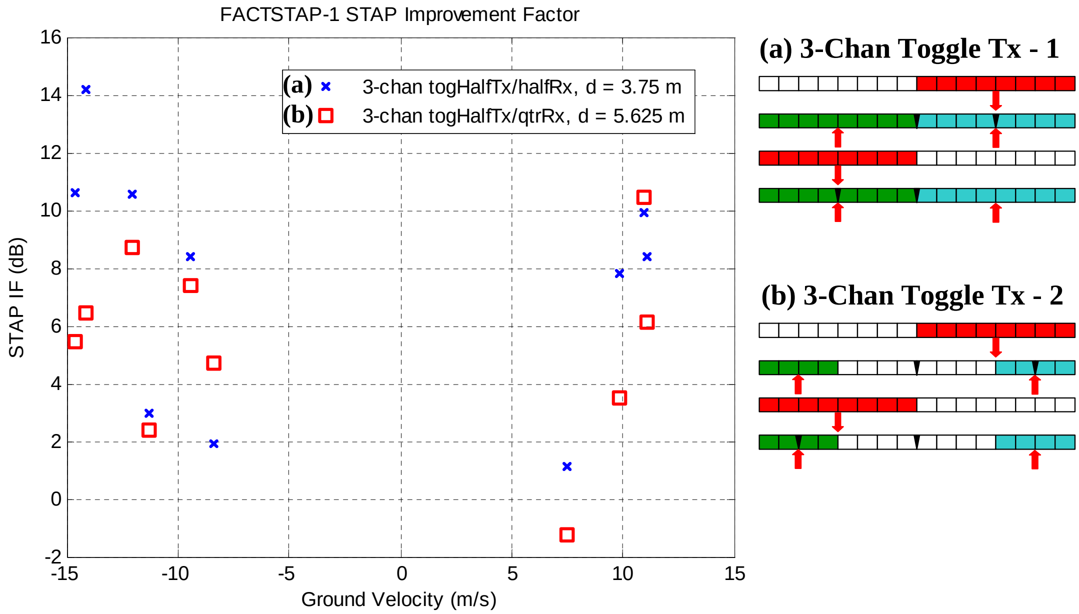


Figure 11: *An IF comparison between the three-channel toggle-transmit mode with its modified toggle-transmit, quarter-aperture receive mode.*

distance at the expense of an even broader azimuth beamwidth and possibly greater clutter-band aliasing results in dramatic deterioration of the detection performance. The very poor performance of this mode may be directly attributed to the significant broadening of the two-way beamwidth, which causes the clutter-band aliasing. There is about 60% broadening of the beamwidth when transitioning from full-aperture transmit and half-aperture receive to half-aperture transmit and half-aperture receive. The broadening increases about 100% over the standard mode when transmitting with half-aperture and receiving with two quarter apertures. This may cause significant main-beam clutter-band aliasing, and the sidelobe interference will certainly affect the STAP clutter nulling performance due to the sidelobes folding back into the main-beam response due to under sampling.

Next, we would like to examine whether there is an observable advantage in using additional virtual channels to improve the detection performance. To accomplish this, we compare the three-channel toggle-transmit mode with the two-channel toggle-transmit mode, as shown in Fig. 12. The inter-phase-center distance for the two-channel toggle-transmit mode is 7.5 m. On the other hand, the three-channel toggle-transmit mode has an inter-phase-center distance of 3.75 m. Trading the large inter-phase-distance for an additional degree of freedom (the third phase center) may or may not lead to an improved detection performance. In this case, however, the STAP IF clearly shows a substantial improvement in the detection performance as seen in Fig. 12. In all cases (except one at -8 m/s), the three-channel mode performs better than the two-channel mode.

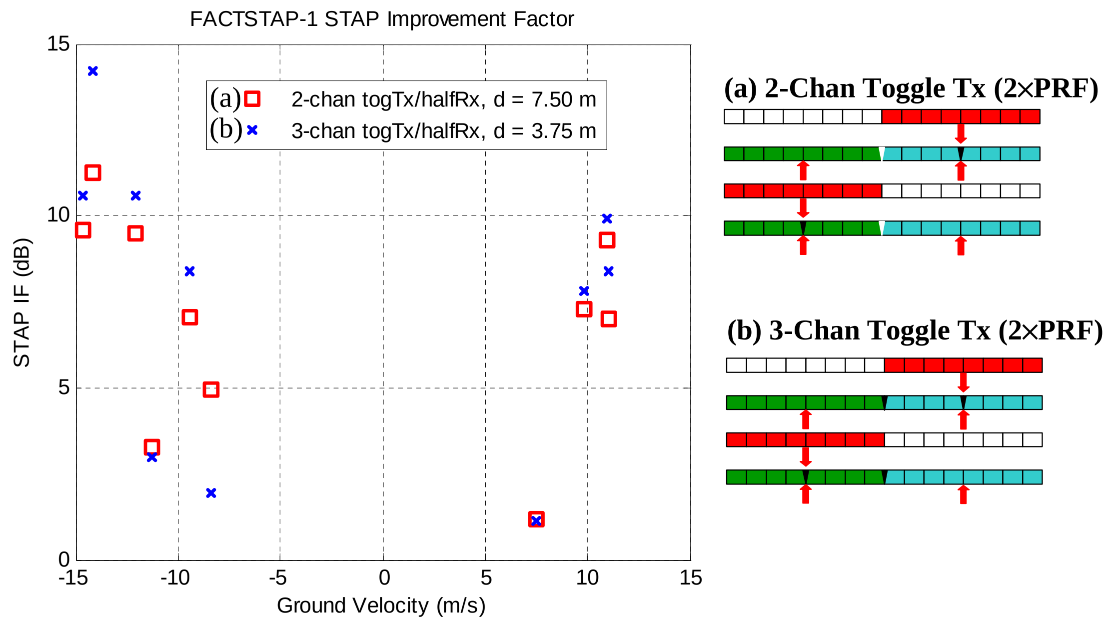


Figure 12: *An IF comparison between the three-channel toggle-transmit mode with the two-channel toggle-transmit mode.*

4.4 Four-Channel Modes

In the next comparison, we examine the four-channel toggle-Rx mode against a true four-channel radar of the same inter-phase-center distance and Tx/Rx antenna sizes. The goal of this test is to examine whether there is a significant deterioration in the detection performance when using the aperture switching for the four-channel case. The result of the comparison is shown in Fig. 13. The result seems to show that there is no clear-cut performance difference between the two architectures. In some cases (lower target velocities), the four-channel toggle-Rx mode appears to have an advantage over the true four-channel radar, but in other cases (higher velocities) the opposite is true; however, even this trend is not clear-cut. From this one test, it cannot be said that the aperture switching has caused any performance deterioration as far as the detection is concerned.

4.5 Registered *vs.* Unregistered Channels

The performance of the Factored STAP applied to registered and unregistered channels is also examined. Usually, for a non-adaptive approach to GMTI, one must first carry out channel co-registration before the channels are processed to null the clutter. For instance, for the non-adaptive DPCA, the inter-phase-spacing, the platform velocity, and the pulse repetition frequency (PRF) must be such that the DPCA condition is adequately met in

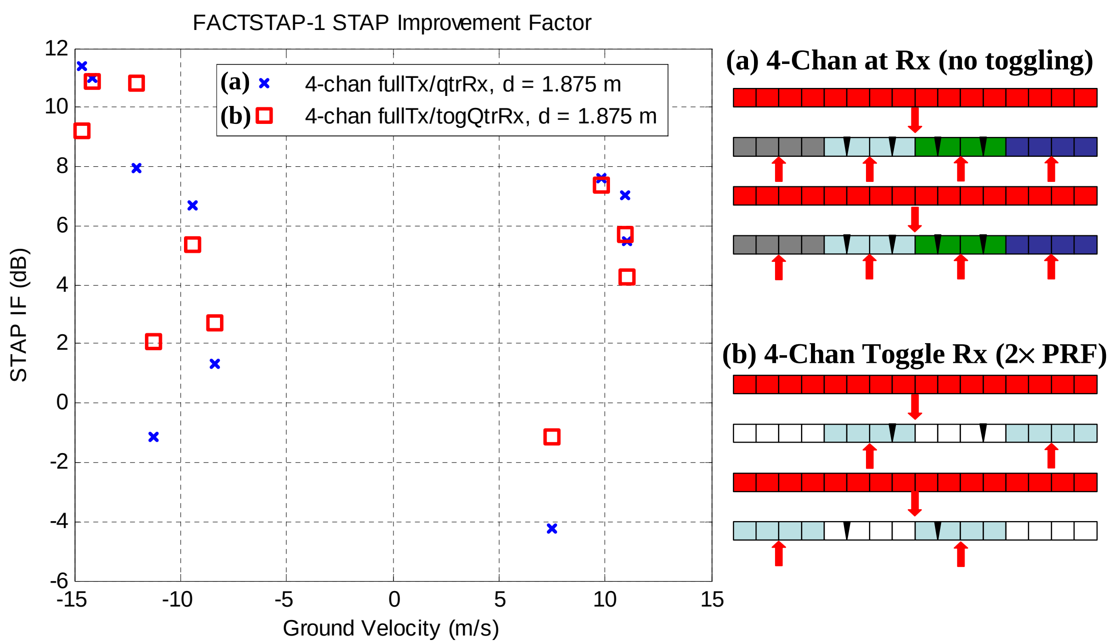


Figure 13: *STAP improvement factor: True four-channel full-aperture transmit and quarter-aperture receive at PRF = 1900 Hz compared to four-channel full-aperture transmit and quarter-aperture toggle receive at PRF = 3800 Hz. 'd' is the along-track baseline between two-way effective phase centers.*

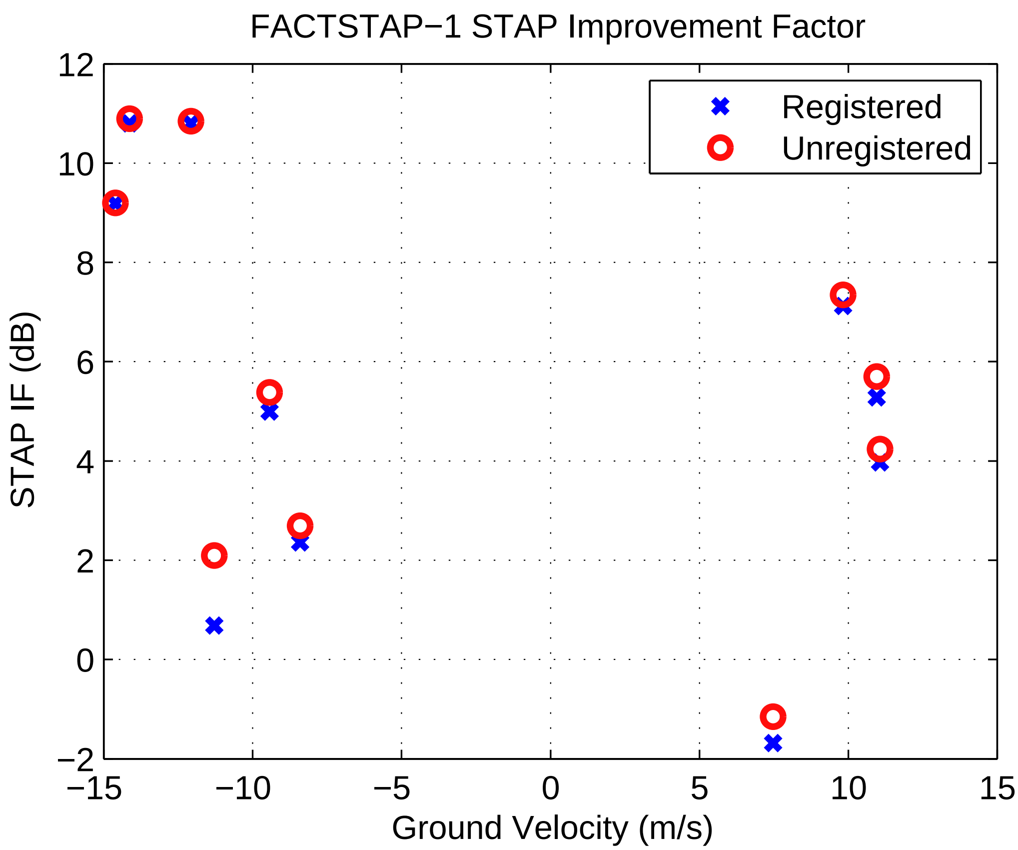
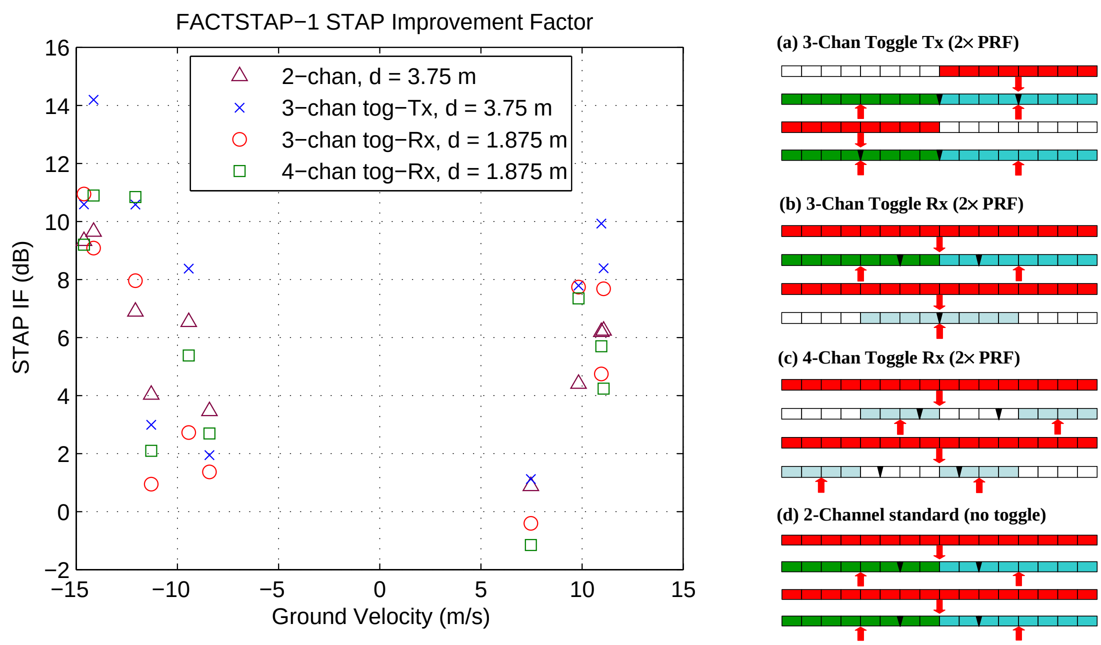


Figure 14: *STAP improvement factor: comparison between registered and unregistered channels of the four-channel toggle Rx mode*

order to effect clutter suppression. This condition is usually very difficult to achieve mechanically. In practice, an electronic or digital approach is employed in order to register the channels such that the scene is sensed by each different “aperture" at the same spatial position but with a small time delay. As long as the signal data is adequately sampled (above the Nyquist sampling), the data can be always shifted forward or backward in time using the FFT interpolation. Since in the toggle modes the scene of interest is sampled by the phase centers (or the virtual channels) at different times and at different spatial positions, the radar echoes received by the trailing phase centers must be interpolated forward in time to register them with respect to the leading phase center in order to effect the DPCA condition. Here, we would like to see whether this registration procedure is necessary or makes any difference in the adaptive clutter nulling. The result of this comparison for the four-channel toggle-receive mode is shown in Fig. 14. As can be seen, there is a very little difference between the registered and unregistered cases. Although not shown here, the same result is also observed for the other proposed modes. Apparently, the adaptivity of a STAP algorithm can handle both registered and unregistered data equally well.



(a) (b)

Figure 15: *STAP improvement factor: Virtual multichannels via sub-aperture toggling at nominal PRF = 3800 Hz. The two-channel standard mode is also shown. 'd' is the along-track baseline between two-way effective phase centers.*

4.6 Virtual Multichannel MODEX Modes

Finally, we use the IF metric to compare between the three proposed virtual multichannel architectures and against the standard two-channel MODEX mode (Fig. 1). The results are shown in Fig. 15. The three-channel toggle-receive mode has the worst detection performance among the three virtual channel schemes and is even worse than the standard two-channel MODEX mode. This is most likely due to its reduced along-track baseline, which is half of that of the standard two-channel mode.

The three-channel toggle-transmit mode has the best detection performance, detecting nine out of ten targets compared to seven targets detected by all the other modes (Fig. 16). The IF metric also shows the same performance superiority of the three-channel toggle-transmit mode. Apparently, the reduced antenna size at transmit does not significantly affect its detection capability. The increased spatial diversity and a large along-track baseline have apparently more than offset the effect of the beam broadening. The four-channel toggle-receive mode performed marginally better than the three-channel toggle-receive mode, but the difference does not appear to be statistically significant. The four-channel toggle-receive mode appears to perform more poorly than the standard two-channel case. This is at first surprising, but considering that the along-track baseline of the four-channel toggle-

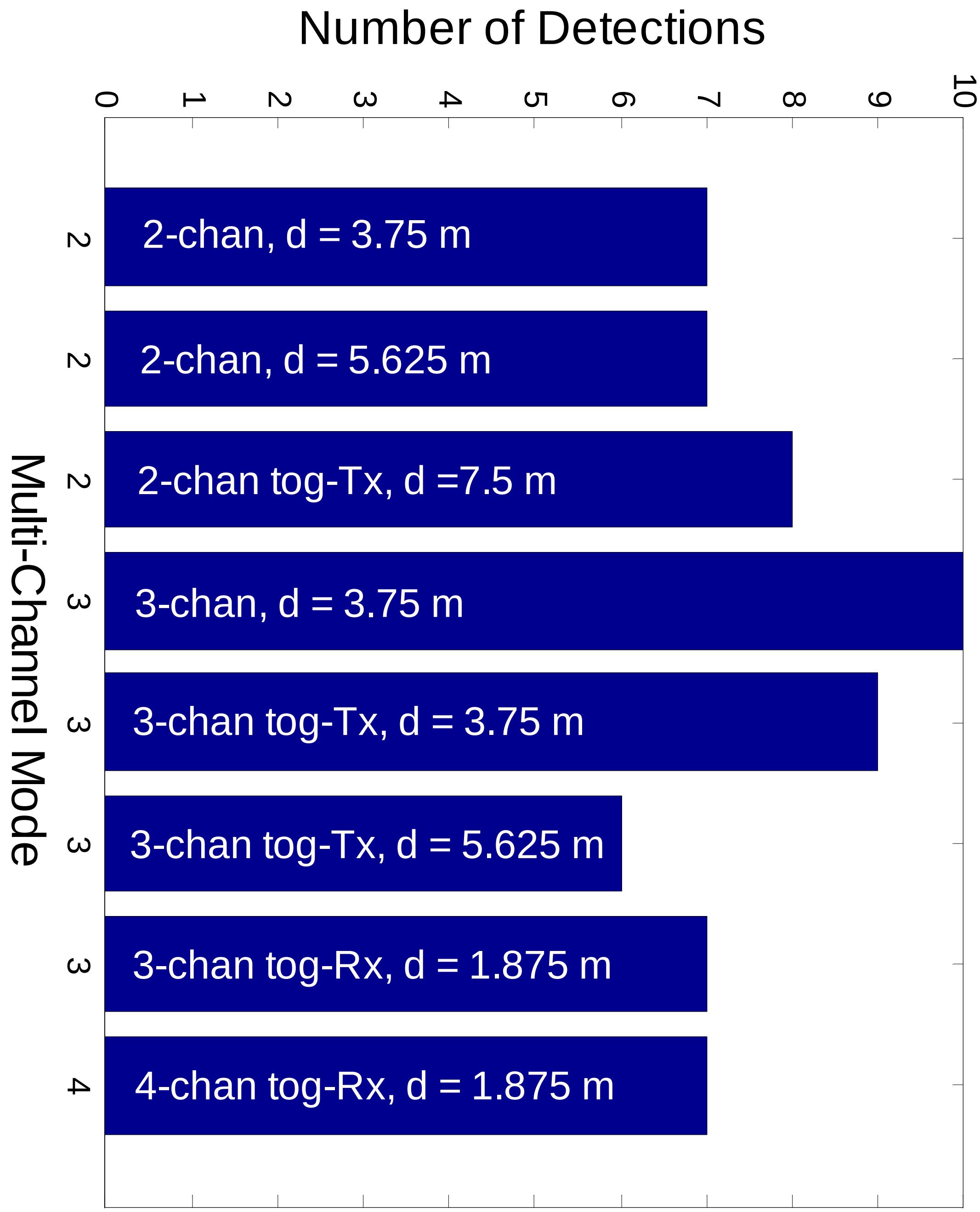


Figure 16: *The number of detections for different GMTI modes.*

receive mode is only half of that of the two-channel mode, the result is not as unexpected as first thought, given that increasing the baseline improves the GMTI performance.

5 Conclusions

The detection performance of virtual multichannel MODEX modes are analyzed and compared with those of a true or ideal three or four channel space-based radar system and the standard two-channel MODEX mode. The results show that there is a small (i.e. statistically insignificant) difference in the detection performance between the virtual multichannel modes and their corresponding true or ideal multichannel radars with the same transmit/receive aperture sizes and along-track baselines. The difference is more noticeable in the three-channel toggle-receive architecture. In general, it can be concluded that the detection performance of a virtual multichannel GMTI radar is comparable to that of a true or ideal multichannel GMTI radar. Comparison between the virtual multichannel modes, including the standard two-channel MODEX mode, shows that the three-channel toggle-transmit mode has a clear detection advantage over the other three proposed MODEX architectures. This can be attributed to the combination of the increased spatial diversity and the large along-track baseline. The benefit of spatial diversity (from multiple channels) will probably be more noticeable in the parameter estimation than in the detection of slowly moving targets, because the increased degree of freedom allows clutter suppression before parameter estimation, minimizing clutter contamination effects on the moving targets. The parameter estimation performance of the virtual multichannel MODEX modes will be the topic for a future study.

References

[1] Stockburger, E.F. and Held, D.N. (1995), Interferometric moving ground target imaging, In *The Record of the IEEE 1995 International Radar Conference*, pp. 438–443.

[2] Chiu, S., Gierull, C.H., and Durak, A. (2005), Clutter Effects on Ground Moving Targets' Interferometric Phase, In *Proc. of IGARSS'05*, Seoul, Korea.

[3] Ender, J.H.G., Cerutti-Maori, D., and Buerger, W. (2005), Radar antenna architectures and sampling strategies for space based moving target recognition, In *Proc. of IGARSS'05*, Seoul, Korea.

[4] Chiu, S. and Gierull, C.H. (2006), Multi-channel concepts for RADARSAT-2 ground moving target indication, In *Proc. of EUSAR'06*, Dresden, Germany.

[5] Gierull, C.H. and Sikaneta, I. (2004), Azimuth phase coding for range ambiguity suppression in SAR, In *Proc. of IGARSS'04*, Anchorage, Alaska, USA.

[6] Nohara, T.J., Premji, A., and Weber, P. (1999), Simulator - Space Based Radar - Volume I: Requirements, Design and User Guide, (Technical Report DND/SST File No.: W7714-8-0141) Sicom Systems LTD.

[7] Chiu, S. and Livingstone, C.E. (2005), A Comparison of Displaced Phase Center Antenna and Along-Track Interferometry Techniques for RADARSAT-2 Ground Moving Target Indication, *Canadian J. Remote Sensing*, 31(1), 37–51.

[8] Dickey Jr., F.R. and Santa, M.M. (1953), Final report on anticlutter techniques, (Technical Report R65EMH37) General Electric Company.

[9] Ward, J. (1994), Space-Time Adaptive Processing for Airborne Radar, (Technical Report 1015) MIT Lincoln Laboratory.

[10] Finn, H.M. and Johnson, P.S. (1968), Adaptive detection mode with threshold control as a function of spatially sampled clutter estimation, *RCA Review*, 29(3), 414–464.

[11] Klemm, R. (1998), Space-Time Adaptive Processing: Principle and Applications, IEE Radar, Sonar, Navigation and Avionics Series 9, London, United Kingdom: The Institute of Electrical Engineers.

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It has been recognized that a two-aperture approach to ground moving target indication is sub-optimum and that target parameter estimation is often compromised by clutter interference or poor signal-to-clutter ratios. This paper investigates the Ground Moving Target Indication (GMTI) performance of several virtual channel concepts proposed for the RADARSAT-2 Moving Object Detection EXperiment (MODEX). These are capable of increasing the spatial diversity of RADARSAT-2 by exploiting its very flexible antenna programming capabilities and allowing the two-channel SAR system to operate like a three or four channel radar. A high fidelity Space-Based Radar Moving Target Indication Simulator (SBRMTISIM) is used to generate virtual channel raw GMTI data for analysis. Moving targets are detected using a combination of the Factored Space-Time Adaptive Processing (Factored STAP) and the Cell-Averaging Constant False Alarm Rate (CA-CFAR) detector. The detection performances of virtual multichannel MODEX modes are analyzed and compared with each other and with those of true or fictitious multichannel space-based radar systems.

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